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TESTS OF 10-INCH 24S-T ALUMINUM-ALLOY SHEAR PANELS WITH $1\frac{1}{2}$-INCH HOLES

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TESTS OF 10-INCH 24S-T ALUMINUM-ALLOY SHEAR PANELS WITH $1\frac{1}{2}$-INCH HOLES

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SUMMARY

Tests were made of a number of 10-inch shear panels of 24S-T aluminum alloy with $1\frac{1}{2}$-inch holes to determine the stress concentration at static rupture and the deformation characteristics. The average factor of stress concentration was found to be about 1.1; reinforcements around the edges of the holes did not increase the ultimate strengths. Permanent set began in specimens without holes at nominal shear stresses of 10 to 12 kips per square inch. In thin specimens with holes, permanent set began at the buckling stress.

INTRODUCTION

In connection with a previous investigation of the strength of shear webs, some tests had been made of 24S-T aluminum-alloy tension specimens 1 inch wide with $\frac{3}{16}$-inch holes (reference 1). These tests indicated a stress-concentration factor of about 1.08 for static rupture. The question arose as to whether this factor could be applied to somewhat larger holes, such as those used to permit the passage of conduits, tubing, or controls through a shear web, and as to how much the stress concentration could be reduced by reinforcing the edges of the holes. The results of a series of tests undertaken to answer these questions are presented herewith. In the course of the tests, information was also obtained on the depth of the shear buckles both under load and after removal of load.

SYMBOLS

a	side of shear frame, inches
d	diameter of rivet hole, inches
D	diameter of hole, inches
E	Young's modulus of elasticity, kips per square inch
P	ultimate load, kips
t	sheet thickness, inches
σ	normal stress, kips per square inch
$\sigma_{y.p.}$	normal stress at yield point, kips per square inch
τ	nominal shear stress, kips per square inch
τ_{cr}	critical shear stress, kips per square inch

TEST SPECIMENS AND PROCEDURE

Material.- The material used was 24S-T aluminum alloy with nominal thicknesses of 0.020, 0.032, and 0.051 inch. The specimens for each nominal thickness were cut from a single sheet. The stress-strain curves for the three sheets are shown in figure 1. The shear panels fail essentially in diagonal tension; the test coupons were therefore cut at an angle of 45° with the grain.

Specimens.- The specimens (fig. 2) consisted of sheets 12 inches square and were bolted into the square-picture-frame jig described in reference 1. The distance between the center lines of the hinge pins of this frame was 10 inches; the clear width of specimen was 8 inches. The edges of the specimens were attached by $^3/_{16}$-inch bolts pitched 1 inch.

The perforated specimens had $1^1/_2$-inch holes. Three types of perforated specimen were tested. (See fig. 2.) The first type had plain holes. In the second type, the edges of the holes were reinforced by turning them up to 45° flanges about $^1/_8$-inch deep. In the third type, the edges were reinforced by riveting two steel rings 1/8-inch thick to the specimen.

The solid specimens either were plain or had steel bosses riveted to them (fig. 2).

Test procedure.- Two different test procedures were used. In procedure A, the load was increased by equal increments until failure occurred. At each load, the depth of the main buckle was measured with a micrometer depth gage. In procedure B, the load was returned to near zero after each reading and the depth of the permanent buckle at this "zero load" was measured.

TEST RESULTS

Ultimate strengths of perforated specimens.- For the specimens with plain holes or flanged holes, the nominal shear stresses τ at failure were calculated by the formula

$$\tau = \frac{0.707P}{t(a - D)} \tag{1}$$

where $a = 10$ inches and $D = 1.5$ inches. At failure, the stress condition in the panels was fairly close to the condition of pure diagonal tension; consequently, diagonal-tension stresses σ were calculated by the formula

$$\sigma = 2\tau = \frac{1.414P}{t(a - D)} \tag{2}$$

In the specimens with rings, the net section was reduced by two holes of diameter d for the rivets used to attach the rings. Formula (2) was therefore replaced by

$$\sigma = 2\tau = \frac{1.414P}{t(a - D - 2d)} \tag{2a}$$

The stresses calculated by formula (2) or (2a) are given in table 1. The stress-concentration factors given in table 2 were obtained by dividing the ultimate diagonal-tension stress given by formula (2) or (2a) into the ultimate allowable stress determined from the test coupons. Figures 3(a) and 3(b) show the factors for the specimens tested by procedures A and B, respectively. The average factor is 1.09 for the first group and 1.11 for the second group. These values are only slightly higher than the value of 1.08 for rivet holes discussed in the Introduction. It is evident from an inspection of figure 3 that neither the flanges nor the steel rings appreciably changed the ultimate strengths of the specimens.

Ultimate strengths of solid specimens.- The ultimate strengths of all solid specimens - plain or with boss - were calculated by the formula

$$\tau = \frac{0.707P}{at} \qquad (3)$$

The stresses shown in table 1 indicate that the presence of a boss riveted to 0.020- or 0.032-inch sheet has little influence on the strength. The specimens with bosses developed about the same stresses as the plain specimens, and failure started sometimes from the edge bolts, sometimes from the boss rivets. In the 0.051-inch specimens, however, the presence of the boss distinctly weakened the specimen, and both specimens tested failed through the boss rivets.

The stresses developed by the plain-sheet specimens are in good agreement with those given in reference 1 if a rivet factor is introduced as described in the reference.

Critical stresses.- The critical shear stresses τ_{cr} of the plain-sheet specimens were computed by the standard formula; the clear width of sheet was used, and the computations were made on the assumption of simply supported edges as well as on the assumption of clamped edges. Inspection of figure 4 indicates that measurable buckles began to appear on the 0.051-inch sheet at a load between the two calculated critical loads. On the two thinner sheets, the appearance of measurable buckles coincides more nearly with the critical load calculated on the assumption of clamped edges. Attempts were also made to determine the critical load by observing the reflection of a rectangular grid on the specimen. On the 0.051-inch specimen the critical load obtained by this method agreed very closely with the load at which measurable buckles began, and the method appeared to be very sensitive. On the thinner sheets, the method could not be used successfully because the sheets were not initially flat.

Permanent set.- Inspection of figure 4 indicates that the plain-sheet specimens began to show permanent set at nominal shear stresses of 10 to 12 kips per square inch. A tentative curve of effective shear modulus was given in reference 2, based on measurements of the change in length of the diagonal of the shear frame; this curve indicated a limit of proportionality in shear of 12.5 kips per square inch. The fact that permanent set in the present tests occurred at somewhat lower stresses than this limit of proportionality can probably be explained by stress concentration along the main buckle. The existence of such a concentration is indicated by the greater depth of the main buckle as compared with the other buckles in the panel and also by some isolated strain measurements. The measurement of the local buckle depth can show this concentration better than the measurement of the length of the diagonal.

In the perforated 0.051-inch specimens, as well as in the specimen with a steel boss, permanent set began at about the same stress as in the plain-sheet specimen. In the 0.032-inch specimens with holes or bosses, however, permanent set started at a much lower stress and, in the 0.020-inch specimens with holes or bosses, permanent set began as soon as the first buckle appeared.

The steel rings did not deform measurably either within their original plane or normal to their plane. The flanged holes elongated about the same amount as the corresponding plain holes. This elongation started at a fairly low stress (fig. 5) and was accompanied by flattening of the flanges. The stiffness of the flanges was not sufficient to prevent the sheet from buckling across the flanged holes.

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REFERENCES

1. Kuhn, Paul: Ultimate Stresses Developed by 24S-T Sheet in Incomplete Diagonal Tension. T.N. No. 833, NACA, 1941.

2. Kuhn, Paul: Skin Stresses around Inspection Cut-Outs. NACA A.R.R., Dec. 1941.

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TABLE I

ULTIMATE DIAGONAL-TENSION STRESSES

[All values in kips/sq in.; on specimens A, the load was increased continuously; on specimens B, the load was reduced to zero after each increment]

Specimen	Perforated specimens			Solid specimens		Coupons (b)
	Plain hole	Flanged hole	Ring	With boss (a)	Plain sheet (a)	
0.020-inch sheet						
A-1	65.7	64.0	64.2	c62.5	------	69.44
A-2	------	66.8	65.4	------	------	
B	63.5	64.2	64.6	d61.2	63.8	
0.032-inch sheet						
A-1	61.8	59.9	59.2	c59.2	------	67.40
A-2	------	57.8	61.0	------	------	
B	60.5	60.8	62.0	d57.4	57.0	
0.051-inch sheet						
A	67.0	63.3	62.2	d56.2	62.2	68.09
B	57.0	61.9	57.5	d54.4	61.4	

[a]No allowance made for reduction of area by 3/16-inch bolt holes.

[b]Average of two tests.

[c]Failure at edge.

[d]Failure at boss.

TABLE 2

STRESS-CONCENTRATION FACTORS FOR PERFORATED SPECIMENS

[On specimens A, the load was increased continuously; on specimens B, the load was reduced to zero after each increment]

Specimen	Type of specimen		
	Plain hole	Flanged hole	Ring
0.020-inch sheet			
A-1	1.057	1.085	1.082
A-2	--------	1.040	1.062
B	1.093	1.082	1.075
0.032-inch sheet			
A-1	1.092	1.125	1.138
A-2	--------	1.167	1.105
B	1.115	1.109	1.087
0.051-inch sheet			
A	1.015	1.075	1.094
B	1.194	1.099	1.183

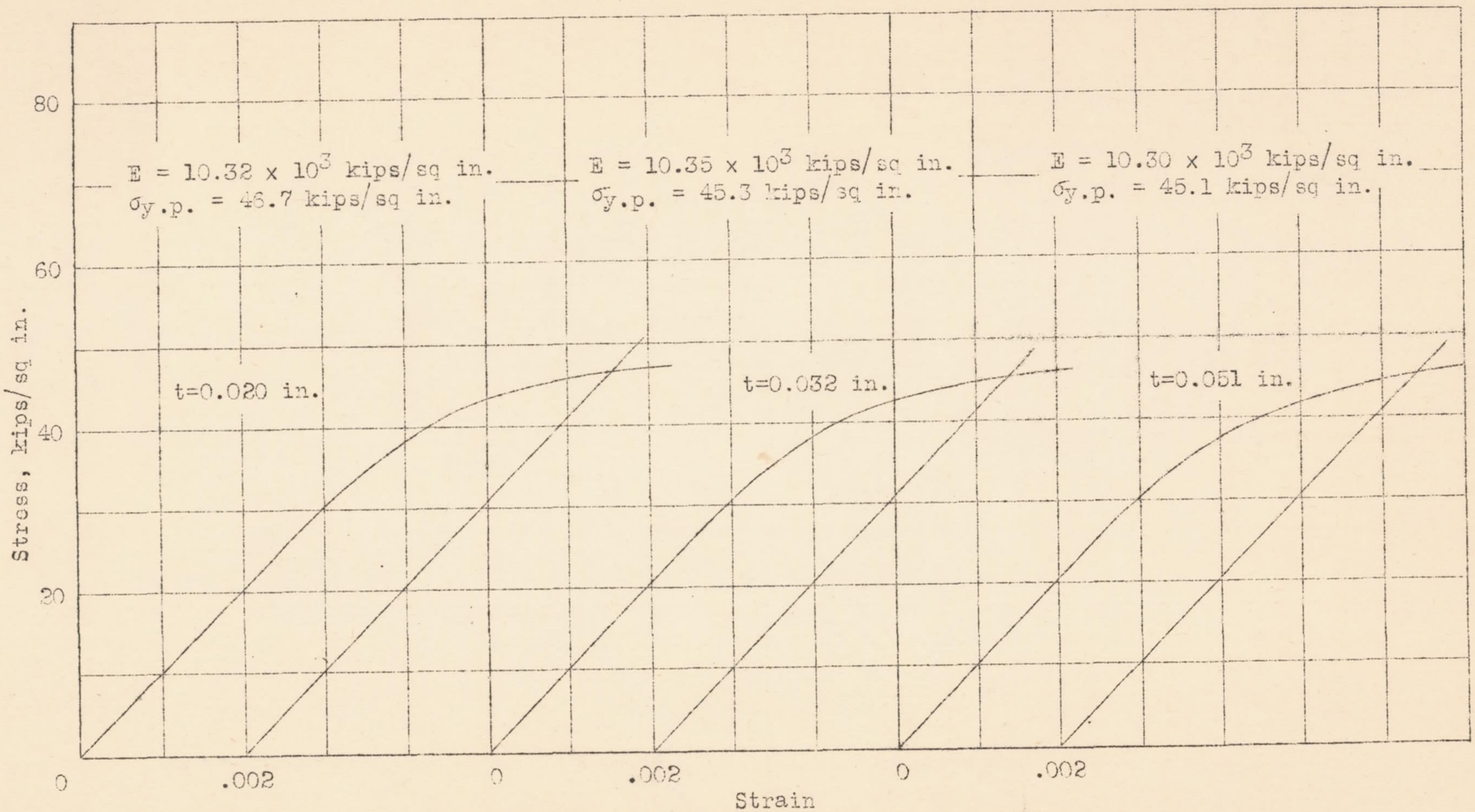

Figure 1.- Stress-strain curves for 24S-T aluminum alloy 45° to direction of rolling.

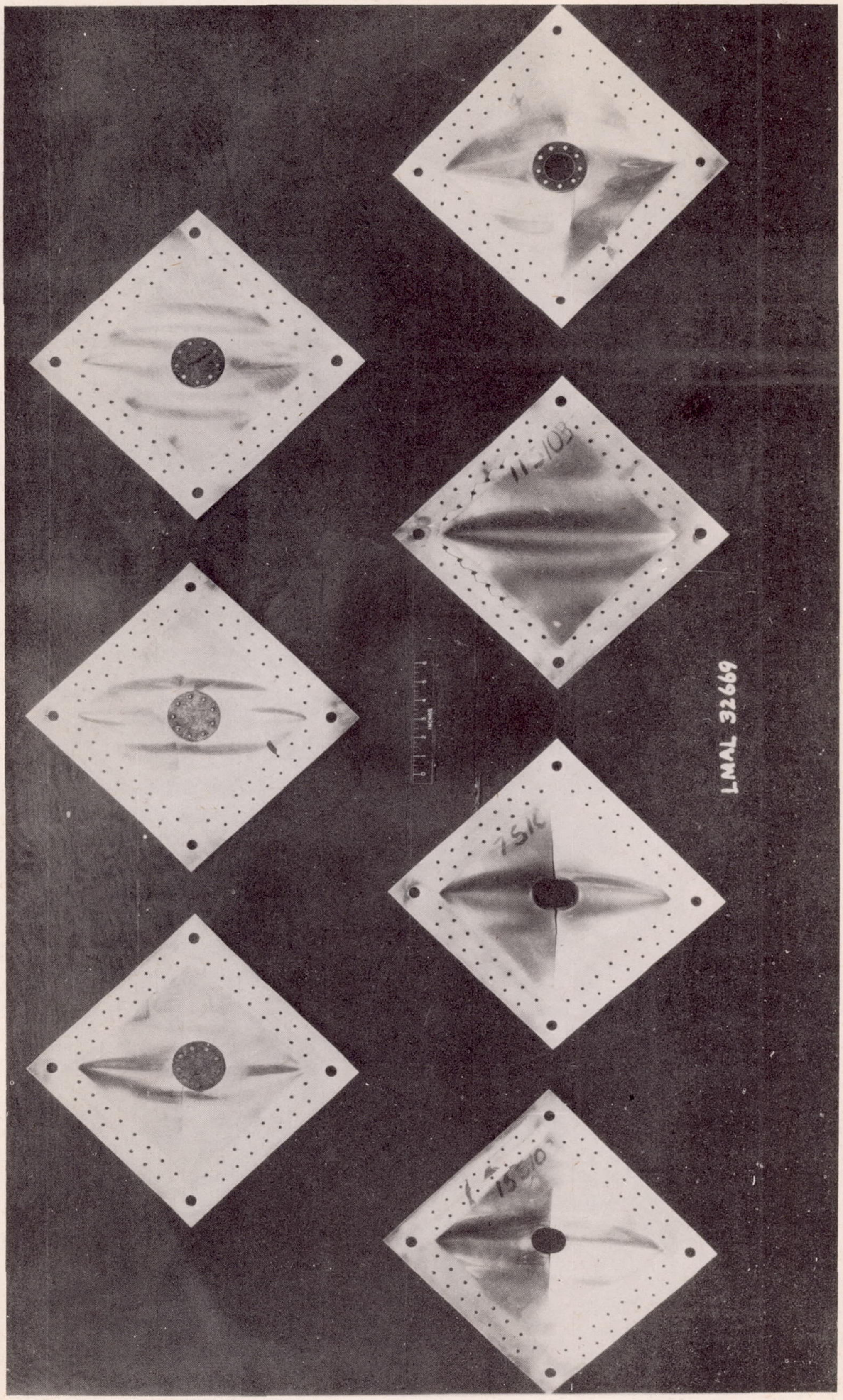

Figure 2. - Typical specimens after failure.

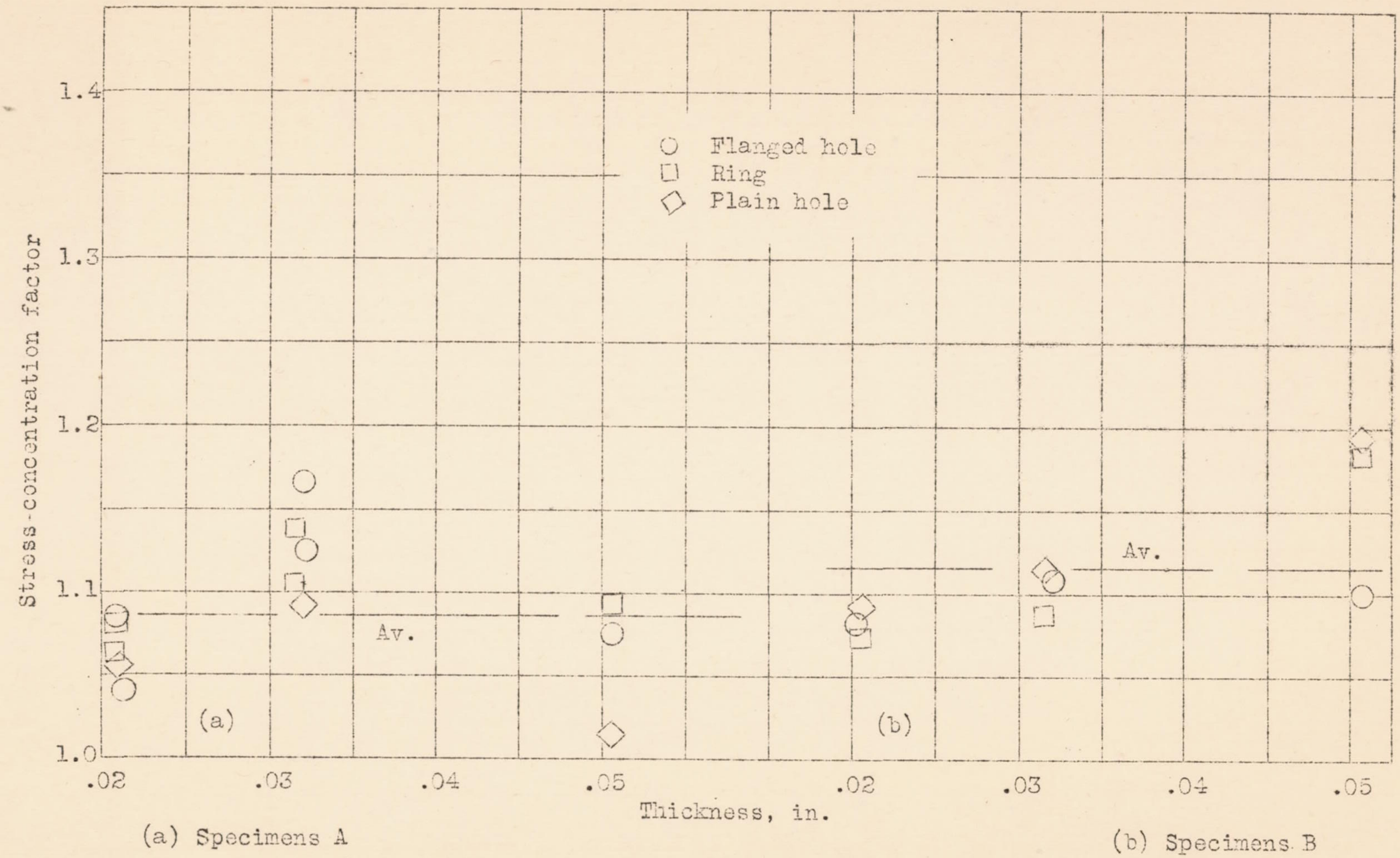

Figure 3.- Stress-concentration factors.

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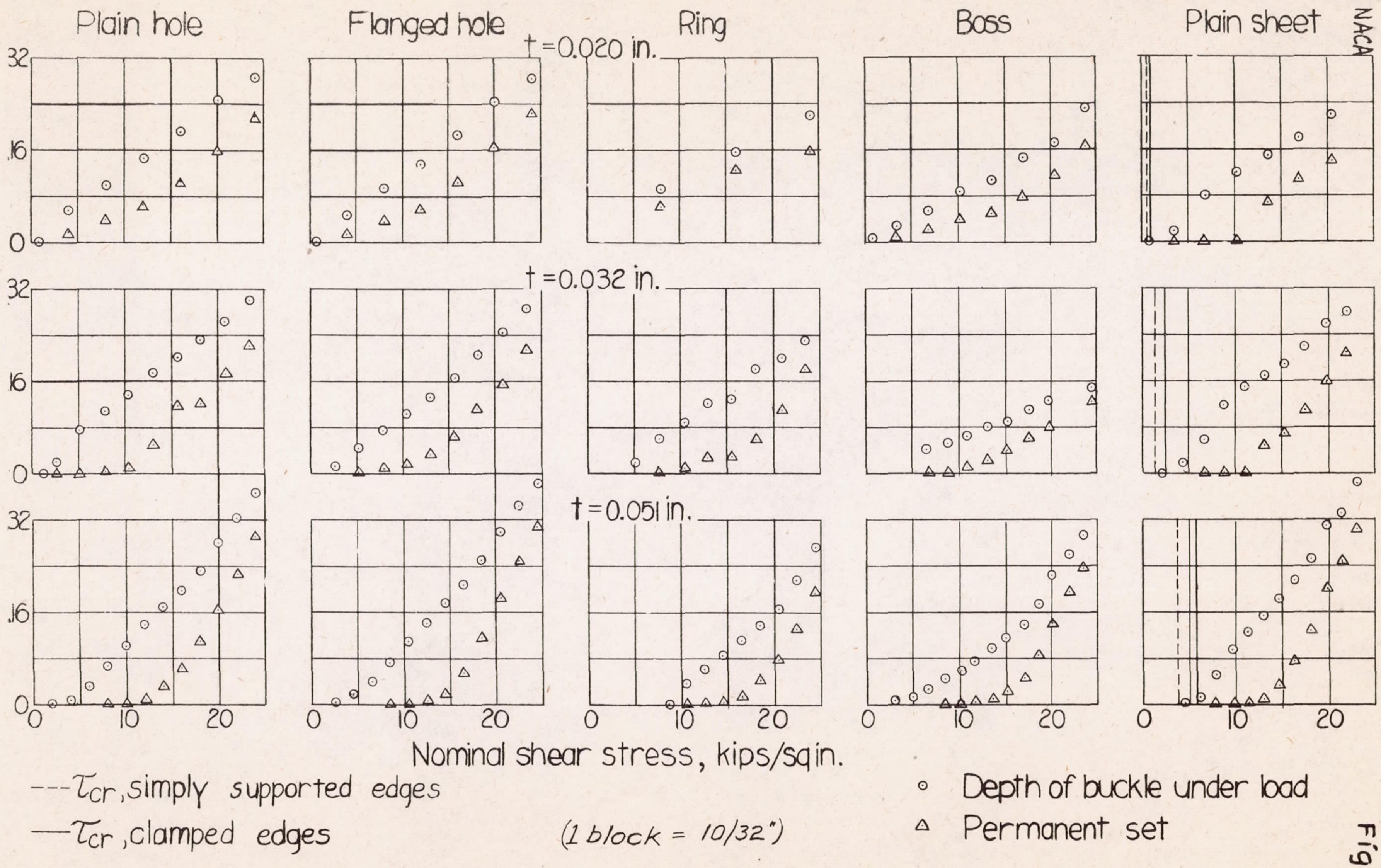

Figure 4.- Stress-deformation curves.

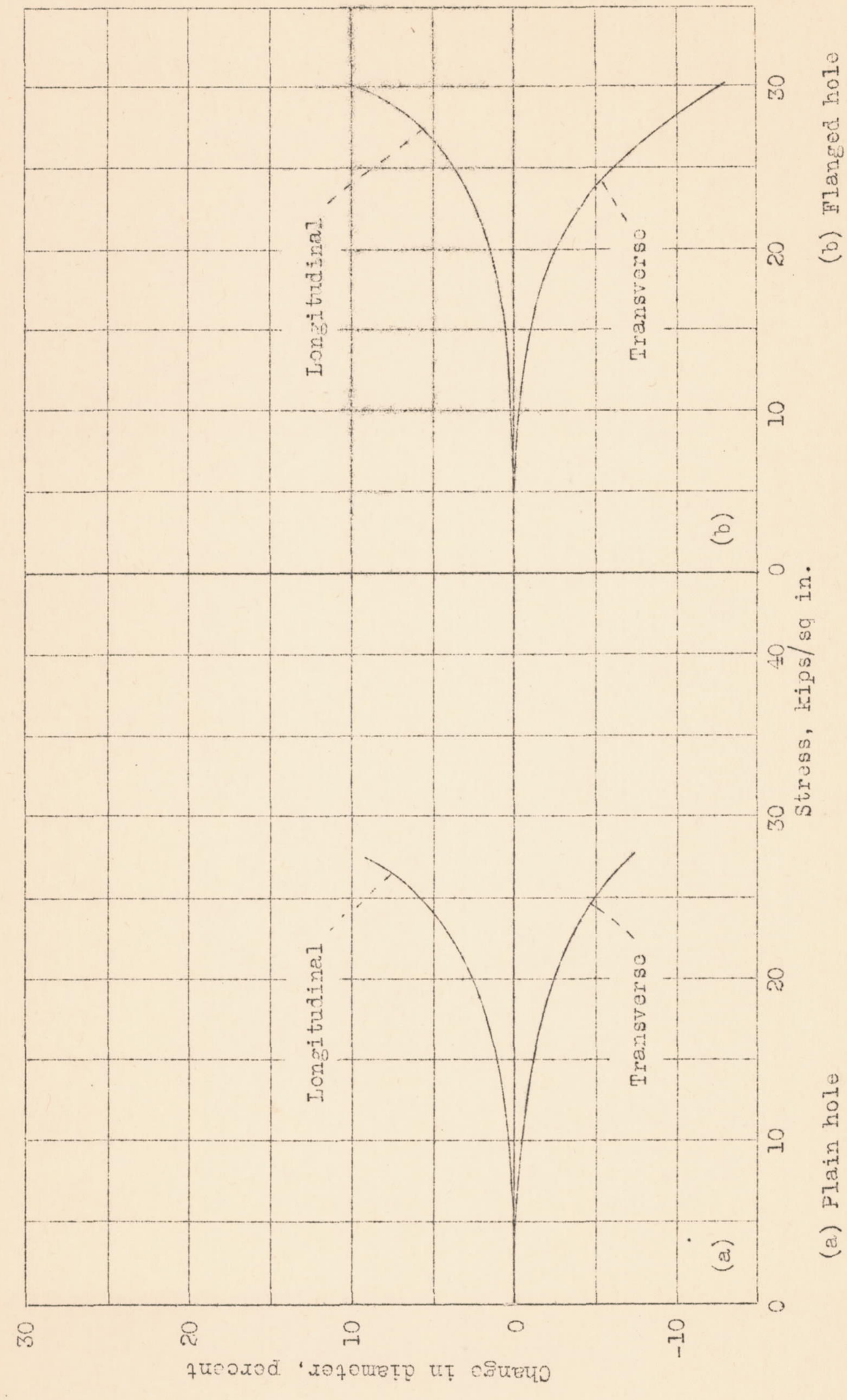

Figure 5.- Change in diameters of holes.